TeV BPM Upgrade Review Comments

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Introduction:
A review of the Tev BPM upgrade hardware with the given charge:

1. Verify that the specification document addresses all relevant components needed for the Tevatron BPM system,
2. Verify that the design approach and schematics are technically sound, self-consistent and reasonably optimized,
3. Check that the design can be implemented in the hardware in a reasonable manner,
4. Suggest improvements and/or concerns regarding the specification.

I was ask at the last moment to lead this review and due to some mix ups with email addresses I was not able to prepare properly for this role. The review was productive, but we did not systematically attend to all aspects of the charge. I add some comments on the specification document at the end of these notes although we did not discuss it during the review.

Timing Card:

The timing card design looks like it is fairly well along and is well thought out. My biggest concern is meeting the 1 ps jitter spec on a card that has so much high-speed digital circuitry on board. Schedules are tight so if there are problems on this card, there will not be time to design another version of the printed circuit board. The clock circuit itself looks well designed although their may need to attenuator added to get the proper drive level to the digitizer. The distribution of the diagnostic signal across the VME backplane to be received by many cards may not be the best solution. Noise and terminations must be looked at closely.

Recommendation: Remove the PLL and clock driver circuit from the timing card and put it in a 1 U rack chassis with a linear power supply. Add a low noise DDS clock to this chassis as an optional source to the VCO. Distribute the diagnostic signals from this chassis as well. As for the source of the diagnostic signal, you could use the high speed DAC signal from the timing card and distribute to all diagnostic cards with precision splitters. A wide band, white noise signal can be used to check the frequency response of the cables, filters and the system as a whole. Problems with converters or the data stream can also be diagnosed.

Diagnostic Card:

My biggest concern here is the use of mechanical relays. The data sheet claims that the initial contract resistance can be as high as 100 mOhm and as low as 30 mOhm. Transitions between this resistance states will change S11 and S21 values by 0.2%. It will be very hard to detect resistive contacts without a tunnel based calibration system. The risk does not seem justified by the questionable value of the injection of the test signal. Some of the specs that would be useful for this card are:

S11, S21, S22 with relay (s) in all states. Understand the filter performance with the Echotek card as a terminator.
Cross talk between channels and noise pick up from digitizers and backplane made with a full crate of electronics.

Recommendation: Remove the series relay and simplify the test modes to inject a signal or not. Even with just this relay, the termination impedance changes from 50 to 25 ohms when the relay closes. As far as board layout is concerned, all RF signals should be imbedded strip lines between ground planes. Pads and other component should be shielded if possible. Use shielded Mini-Circuit pads instead of resistors. Remember that 53 MHz is 21 times higher in frequency than the 2.5 MHz Recycler system so crosstalk is 21 times worse.

Hardware Specification Document:
Good results are reported for the test system installed in the Tevatron. I have been out of the loop for a while, so I have not seen these results myself. Therefore my comments are purely theoretical and not based on measured data. Errors of any measurement system are the sum of calibration errors, drifts, noise and systematic errors that may be dependent on parameters other than the one that is the focus of the measurement.

Calibration: It seems that there is no provision for electrical calibration of the system. The only way to make a calibration that includes cables and all of the signal chain is to inject a signal close to the detector in the tunnel. This is not easy and probably need not be done at this time. It seems like a good idea for the long run for the project.

Drifts in this system all come from gain variation from channel to channel electronics and cables. These are hard to control and track other than with the use of a calibration system.

Noise: Random noise should not be a big issue for this system. There is a lot of signal coming from the detectors, so the dominant noise source should be the quantization noise of ADCs which have a noise figure of about 30 dB. This means the system should have a S/N of about 150 dB/Hz if details are paid attention to. Sub micron RMS variation at the requested 10 Hz BW should be easily achieved. Probably 6 to 8 dB on S/N may be lost due to the wider bandwidth filters that are specified. I understand that this is to make possible single bunch measurements, but it does come at a cost.

Systematic Errors are the toughest to deal with and the thing that is potentially most troubling as no amount of post processing will remove them. There are a couple of aspects of the current design that are possible sources of systematic error. Synchronous sampling is being employed because of its observed reduction in noise. What is reduced is not random noise, as the choice sample frequency can not have an effect on random signals. Instead it is mixing down IM products to baseband where they are added to the desired beam signal. The IM product vectors phase may be phase dependent on the clock to beam phase. Synchronous sampling gives worst case sensitivity to the ADC DN because only a few local values of the ADC are used instead of averaging over a large region of the ADC transfer function. Again, none of these errors show up as “noise” as they sum up with the baseband signal and translate to a position error that may be dependant on bunch phase and shape.

The hardware document talks about closed orbit measurements being made as an average of up to 1024 turn by turn measurements as is done in the present system. In the frequency domain this translates to a sync function shape with the central lobes 100 Hz wide. This filter will do nothing to reduce 33 Hz synchrotron motion, which is one of the biggest problems with the present Tev BPM system. Averaging positions instead of averaging raw IQ data is like reducing the video bandwidth on a spectrum analyzer while keeping a wide resolution bandwidth. The noise appears to be reduced but accuracy is not improved.

Recommendation: Provide a mode to make a pure narrow band measurement using 100 Hz BW filters on the I and Q data streams. Calculate positions to provide the required 100 Hz BW data. Filter the 100 Hz data down to 10 Hz for the required 10 Hz BW data. Use a low noise crystal 80 MHz clock source for measurement.

Conclusions: Time is the biggest enemy of this project even though good progress is being made. Rapid prototyping needs to take place so that a few channels can be installed in the ring ASAP. Full specification and testing of all components in the signal chain will be key to success. We all look forward to the Tev benefiting from this project!